

## Calibration Certificate

**Calibration provided by :** EKO Instruments Co., Ltd.  
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|                      |                           |                         |                 |
|----------------------|---------------------------|-------------------------|-----------------|
| Manufacturer :       | EKO Instruments Co., Ltd. | Issue Date :            | May 10, 2023    |
| Model :              | MS-711                    | Calibration Date :      | April 28, 2023  |
| Description :        | Spectroradiometer         | Calibration Procedure : | 110225-1.1      |
| Serial Number :      | S17157.04                 | Calibration method :    | Lab calibration |
| Accessories :        |                           |                         |                 |
| Certificate Number : | S17157.04-EX23-229        |                         |                 |

### Calibration uncertainty

| Wavelength range                        | Combined uncertainty | Exposure time settings |
|---|----------------------|------------------------|
| 300nm - 350nm                           | +/- 18 %             | 1000ms                 |
| 350nm - 450nm                           | +/- 6 %              | 500ms                  |
| 450nm - 1050nm                          | +/- 5 %              | 500ms                  |
| 1050nm - 1100nm                         | +/- 5.6 %            | 1000ms                 |
| 350nm - 1100nm<br>(wavelength accuracy) | +/- 0.2nm            | -                      |

### Calibration condition

| Conditions                       | Unit              | Note |
|----------------------------------|-------------------|------|
| Ambient temperature              | 25 °C             | -    |
| Orientation of lamp filament     | Vertical          | -    |
| Orientation of spectroradiometer | 90 degrees Tilted | -    |

### Standard lamp

|                  |                           | Note          |
|------------------|---------------------------|---------------|
| -                | -                         |               |
| Lamp type        | OL-FEL-C Tungsten Halogen | 1000W         |
| Lamp S/N         | F1746                     | -             |
| Calibration date | 2022/12/1                 | Max. 50 hours |



M.Tanioku/ Manager of Mfg. Dept.



H.Yamato/ Inspector

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## Calibration procedure

The MS-spectroradiometer is calibrated against a NIST traceable tungsten-halogen OL-FEL standard lamp at a distance of 50 cm. The standard lamp has a known spectrum and the absolute irradiance is calibrated at several wavelengths. By measuring the spectroradiometer's detector responsivity in counts as a function of the irradiance at corresponding wavelengths, the sensitivity of each photo diode array pixel is converted into absolute units ( $W/m^2/\mu m$ ).

The calibration function is determined by averaging 10 single measurements, measured separately for 4 different wavelength intervals each with a fixed exposure time. This is to use optimal output characteristics of the detector. Finally the calibration function is uploaded to the spectroradiometer firmware for automatic conversion of measured count into absolute units.

## Calibration Uncertainty

The combined uncertainty of the calibration function for each wavelength interval is based on individual uncertainties contributed by the standard lamp, calibration set-up and spectroradiometer performance properties.

| Source                    |                    | Uncertainty |             |             |              |
|---------------------------|--------------------|-------------|-------------|-------------|--------------|
|                           |                    | 300 - 350nm | 350 - 450nm | 450 - 900nm | 900 - 1100nm |
| Standard Lamp calibration | Gooch&Housego      | 5.10%       | 3.90%       | 3.40%       | 2.30%        |
| Lamp current              | Calibration set-up | 0.12%       | 0.09%       | 0.04%       | 0.02%        |
| Measurement repeatability | Spectroradiometer  | 6.00%       | 1.00%       | 1.00%       | 2.00%        |
| Non-Linearity             | Spectroradiometer  | 1.00%       | 1.00%       | 1.00%       | 1.00%        |
| Alignment                 | Calibration set-up | 1.00%       | 1.00%       | 1.00%       | 1.00%        |
| Temperature dependency    | Spectroradiometer  | 0.25%       | 0.25%       | 0.25%       | 0.25%        |
| Cosine response           | Spectroradiometer  | 0.00%       | 0.00%       | 0.00%       | 0.00%        |
| Stray Light               | Spectroradiometer  | 6.00%       | 1.50%       | 0.60%       | 0.60%        |

$$\text{Uncertainty} = \left\{ \left( \text{Standard Lamp calibration} / 2 \right)^2 + \left( \text{Lamp current} / 2 \right)^2 + \left( \text{Measurement repeatability} \right)^2 + \left( \text{Non - Linearity} \right)^2 + \left( \text{Alignment} \right)^2 + \left( \text{Temperature dependency} \right)^2 + \left( \text{Cosine response} \right)^2 + \left( \text{Stray Light} \right)^2 \right\} / \sqrt{2} * 2$$

## Traceability to NIST Standard

OL-FEL lamps are calibrated by direct comparison to a Gooch & Housego NIST traceable FEL 1000-Watt lamp. Gooch & Housego NIST traceable lamps are used for a maximum period of 50 hours (will be replaced afterwards).

